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CALCULATED NEAR FIELDS OF NAVY HF
WHIP ANTENNAS:

J. W. Rockway, et al

Naval Electronics Laboratory Center
San Diego, California

24 April 1973

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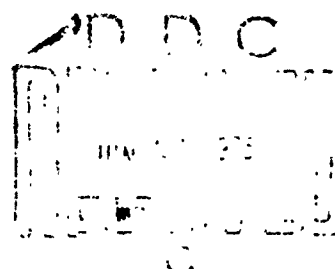# CALCULATED NEAR FIELDS OF NAVY HF WHIP ANTENNAS

Establishes preliminary guidelines on the size of personnel and ordnance radiation-hazard zones.

J. W. Rockway and P. M. Hansen

Research and Development

24 April 1973

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13 ABSTRACT

The hazards to personnel, ordnance, and fuel caused by shipboard hf radiators are determined. Numerical techniques are used to calculate the peak field intensities produced by 1-kW power input to standard Navy whip antennas in configurations similar to shipboard geometries. Preliminary guidelines are established indicating the size of the hazardous region surrounding the antenna for both ordnance and personnel.

Details of illustrations in
this document may be better
studied on microfiche

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KEY WORDS	LINK A		LINK B		LINK C	
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PROBLEM

Calculate field intensities arising from hf radiators on shipboard, and determine the hazards to personnel, ordnance, and fuel caused by these radiators.

Recommend methods of reducing these hazards.

RESULTS

Numerical techniques are used to calculate the peak field intensities produced by 1-kW power input to standard Navy whip antennas in configurations similar to shipboard geometries.

Preliminary guidelines are established indicating the size of the hazardous region surrounding the antenna for both ordnance and personnel.

RECOMMENDATIONS

1. Maintain hazard zones around shipboard transmitting antennas. These zones should ensure that personnel and ordnance keep the proper distance from the antenna. For 35-ft whip antennas, the clearance is specified in the recommendations section.

2. Verify the calculations by measurement.

3. Extend this analysis to cover other shipboard antennas. Specifically, whips of length other than 35 ft, corner-mounted whips, twin whips, discone/discage antennas, and fan antennas should be treated.

4. From the results of 3, develop design charts detailing the minimum hazard-zone radius for each type of antenna, including the effects of various possible mounting configurations.

ADMINISTRATIVE INFORMATION

Work was performed by the Radio Technology Division (Code 2100) from July 1972 to February 1973 under direct funding (NELC P201) from the Electromagnetics Technology Department (Code 2000). This report was approved for publication 24 April 1973.

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INTRODUCTION: THE NEAR-FIELD PROBLEM

BACKGROUND

Because shipboard operations are carried out within fixed (small) distances from hf transmitting antennas, the Navy has a unique and long-standing operational problem the radiation from these antennas can be hazardous to personnel, ordnance, fuel, and electronic equipment due to the intensity of the fields in close proximity to the radiating element.

Accordingly, the Navy has been pursuing the study of the near fields of antennas for a number of years. However, the near-field structure is very complex, and previous theoretical analysis has only been practical for very simple antennas in uncomplicated geometrical settings. But with the advent of the modern high-speed computer, approximate solution techniques such as the method of moments became practical. This technique is suitable for the calculation of the electromagnetic fields anywhere, including in close proximity to the radiating element; and the degree of accuracy of the solution is a function of the number of computations done to obtain that solution (computer time). Convergence tests are available which help to determine when the desired accuracy has been obtained.

SCOPE OF THE STUDY

This study is limited to calculating the near fields of standard Navy hf whip antennas. The two lengths considered are the standard 35-ft whip and a half-length (17½-ft) whip. Three different geometrical configurations are studied: (1) whip on a groundplane; (2) whip on a groundplane near a wall; and (3) whip on a groundplane near a corner. In all cases, the surfaces are assumed to be perfectly conducting; this is a valid assumption for ship structures at hf. Also, all the walls are assumed to be infinite in extent, thus allowing the use of image theory and facilitiating computation. However, it is felt that for peak field intensities the infinite wall cases give an upper bound, with the possible exception of edge regions. Work is currently being done on modeling finite groundplanes and walls.

RADIATION HAZARDS (RADHAZ)

A brief literature review was undertaken to determine what parameters of the hazardous fields near a radiating element would be important to this study. More complete studies of radiation hazards (RADHAZ), in particular with respect to the Navy's needs, are contained in referenced publications by NAVELEX[1] and NAVAIR.[2]

RADHAZ TO PERSONNEL

With certain reservations, physiologists and biologists generally agree that radiation damage to personnel is primarily a heating effect. If the "non-thermal" effects are neglected, the hazard is electric-field intensity The body

can be characterized as a lossy dielectric;[3] thus, the heating due to dielectric and conductive losses is much greater than the heating due to magnetic losses.

In the microwave region, the minimal hazard is 10 mW/cm.[2] However, power density is not a meaningful concept in the near field. Instead, the electric-field intensity 194 V/m is the generally accepted standard. 194 V/m is the far-electric-field intensity of the power density 10 mW/cm.[2]

For the hf region, however, the 194-V/m level is generally believed to be too conservative.[4] For example, on the basis of their analysis and experimental work, Rogers and King[5] suggest that under plane-wave conditions (far field) an electric-field strength of 1000 V/m is considered to be the safety limit for continuous exposure to radio-frequency radiation in the range below 30 MHz.

Hf radiation is widely conceded to be less of a biological hazard than microwave radiation but the hf radiation hazard still exists. In the civilian society, large hf radiation is rarely encountered: in the ship environment, however, it may be common. Apparently, more work is needed to better define the hf standard. For the purpose of this study, 1000 V/m will be used as the hazardous level for personnel.

RADHAZ TO ORDNANCE

Hazards of electromagnetic radiation to ordnance (HERO) stem from the use of sensitive electroexplosive devices (EED) in ordnance systems. The EED's can be prematurely activated or degraded by high-intensity rf fields. In addition, EED firing characteristics can be altered by electromagnetically induced heating.

The Naval Ordnance Systems Command has established classifications of susceptibility pertinent to HERO. Susceptibility refers to the actual induction of measurable rf energy into an EED in an ordance system. The degree of susceptibility is dependent upon the amount of induced energy, the characteristics of the EED, and the environment.

Items that are negligibly susceptible and require no field-intensity restrictions beyond the general requirements during all phases of normal employment are classified HERO SAFE ORDNANCE. Items that are moderately susceptible and require moderate field-intensity restrictions for at least some phases of employment are classified as HERO SUSCEPTIBLE ORDNANCE. Items that are highly susceptible and require severe field-intensity restrictions for some or all phases of employment are classified as HERO UNSAFE ORDNANCE. The HERO SAFE ORDNANCE classification should be maintained only when general HERO requirements are met and authorized handling procedures are followed. At frequencies of 2 to 32 MHz, when the electric-field intensity exceeds 100 V/m, HERO SAFE ORDNANCE can become HERO UNSAFE ORDNANCE.

RADHAZ TO FUEL

The potential RADHAZ here is the induced ignition of volatile fuel-air mixtures by rf energy. The three requirements for an inadvertent ignition are:

1. Presence of a proper fuel-air mixture

2. A correctly sized gap across which the spark occurs

3. Sufficient spark energy and time duration

From actual measurements, it has been determined that a spark of energy of 50 V-A is required to ignite gasoline in an explosive vapor test device. Recently, some attempt has been made to relate the fuel hazard to electric-field intensity. The primary result has been to show that the igniting electric-field intensity is a function of frequency, and is a minimum in the upper hf band.

APPROACH

THE METHOD OF MOMENTS

Electromagnetic radiation problems can always be represented by an integral expression with an inhomogenous source term. However, until the advent of the high-speed digital computer, such representations were often academic. They could not readily be solved for the electric current, from which all parameters of an antenna system can be determined. Now these integral equations can be solved. The unifying concept in this numerical treatment of radiation problems is the method of moments.[6]

The method of moments essentially involves a reduction of the associated integral equation to a system of linear algebraic equations, where the unknowns are usually coefficients in some appropriate expansion of the current. The resulting matrix equation can then be solved for the current by a high-speed digital computer.

Computer programs based on the method of moments were developed independently at NELC by the authors. The Pocklington integral formulation was used, which is valid only for thin linear antennas.

The Pocklington integral equation may be written[7]

$$F_z^i = \frac{i}{\omega \epsilon} \int_{-L/2}^{L/2} I(z') \left[\frac{\partial^2 G(z,z')}{\partial z^2} + k_0^2 G(z,z') \right] dz_0' \qquad (1)$$

where

$$G(z,z') = \frac{e^{-ik_0 r}}{4\pi r}$$

and r is measured from the source point to the observation point. All of the current is assumed to flow on the axis of the wire antenna. This is the

intregro-differential equation that must be solved. E^I is the known exitation source, and I is the unknown response function to be determined.

The method of moments is used to reduce this integral formulation to an algebraic matrix equation. Each wire antenna is divided into N sections. If each wire has length h, each subsection has length

$$d = \frac{h}{N}$$

The total current flowing on the wire can then be written

$$I(z) = \sum_{n=1}^{N-1} C_n I_n(z) \tag{2}$$

A piecewise sinusiodal basis function is used. Thus,

$$I_n(z) = \frac{C_n \sin k_0 (z_{n+1} - z)}{\sin (kd)} \qquad z \epsilon [z_n, z_{n+1}]$$

$$I_n(z) = \frac{C_n \sin k_0 (z - z_{n-1})}{\sin (kd)} \qquad z \epsilon [z_{n-1}, z_n] \tag{3}$$

The current flowing on each wire antenna is approximated by a series of overlapping piecewise sinusoidal current dipoles (fig. 1). Note that zero current is ensured on the ends of the wire antennas.

Figure 1. Example of a piecewise sinusoidal basis function for six overlapping dipoles.

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If equation (3) is substituted into (1), and the resulting equations are forced to match boundary conditions for E^i at n different match points, a linear algebraic matrix equation is derived

$$E_n^i = S_{mn} C_n \qquad (4)$$

where

$$S_{mn} = \frac{j30}{\sin(kd)} \left(\frac{e^{-jkr_{n-1}}}{r_{n-1}} + \frac{e^{-jkr_{n+1}}}{r_{n+1}} - \frac{2\cos(kd)\, e^{-jkr}}{r} \right)$$

S_{mn} is the exact closed-form solution of the vertical fields resulting from a dipole with a piecewise sinusoidal current distribution,[8] (see fig. 2). The matrix equation (4) is then solved for the unknown coefficients C_n. The matrix solution techniques of Wilkinson[9] are used.
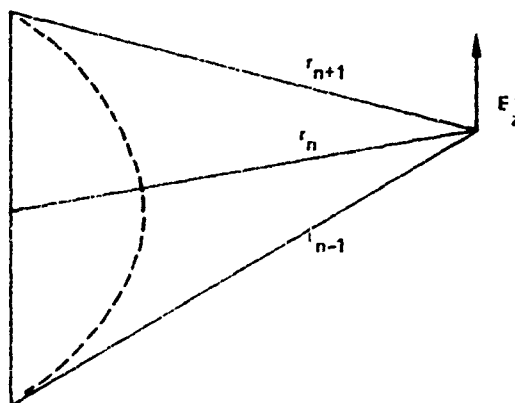
Figure 2. Electric field resulting from a dipole with piecewise sinusoidal current distribution.

The match points of equation (4) are always on the surfaces of the wire antennas. Since the wire antennas are perfect conductors, E^i is zero, except where the exitation of the antenna occurs. The fields at points where the exitation voltage has an effect are determined from one of two source models: (1) the delta gap[10] or (2) the magnetic frill.[11]

Actually, in the computer programs, the current is considered to be a tubular sheet on the surface of the thin wires, while the electric field is evaluated on the wire axis. The form of the Pocklington equation is not changed by using this convention.

Once the current distribution is computed, all effects of the antenna structure can be determined. The near-field values are calculated by the method described by Adams, Baldwin, and Warren.[12] The peak electric-field strength is not directly related to the sum of the squares, and must be calculated by the method described by Adams and Mendelovcez.[13]

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THEORETICAL ANTENNA ARRANGEMENTS

Four hf antenna arrangements are considered for the near-field computations. The first two cases have the whip antenna situated on an infinite perfectly conducting ground plane. (See figure 3 under NEAR-FIELD-CALCULATION RESULTS.) In case 1, the antenna is 35 ft high (10.62 m). In case 2, it is 17½ ft high (5.33 m). These two cases represent an attempt to determine the effect of surrounding structure on the near-field distribution. Case 3 is a 35-ft whip on a ground plane and near a vertical plane (see figure 13). Case 4 is a 35-ft whip on a groundplane and near two vertical intersecting planes (see figure 19). In all cases, the antenna and the surrounding planes are perfectly conducting.

The basic element of each antenna arrangement is the base-fed whip. In cases 1, 3, and 4, it is 35-ft in length and has a constant radius determined by $\Omega = 12.5$.* In case 2, it is 17½ ft in length and has the same constant radius with $\Omega = 11.11$. One kW of power is delivered through the coupler, an AN/URA-38, to the antenna. The efficiency of this coupler is taken into account in the calculation of the near fields.

COMPUTATIONAL ACCURACY

In case 1, the calculated impedances compare within 10% to the results of King.[14] This comparison verifies the general method. The calculation of impedance and near fields requires a significantly more accurate knowledge of the current distribution on the antenna structure than the calculation of the far field.[15] Similarly, the impedance requires a more accurate current distribution than the near fields. At 2 MHz and 1 m from the antenna, the near-field calculation for a reasonable current distribution will be at least four times more accurate than the impedance. Accuracy, then, improves quite rapidly with distances away from the antenna.

Thus, the near fields of the various Navy 35-ft whips will be approximately the same. The actual fields will vary little from the following computations. At 2 MHz and 1 m from the whip, a conservative estimate of the error is 10 to 20%. Again, this error will decrease rapidly with distance away from the antenna.

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*Ω is defined as $2 \ln (2h/a)$, where h is the height of the antenna, and a is the radius.

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35-ft WHIP ON A GROUNDPLANE

This antenna arrangement, case 1, is represented pictorially in figure 3. The near fields at frequencies of 2, 4, 6, and 10 MHz are shown in figures 4A, 5A, and 6A for vertical heights, Z, of 1, 2, and 10 m, respectively. At frequencies 15, 20, 25, and 30 MHz, the near fields at vertical heights 1, 2, and 10 m are shown in figures 4B, 5B, and 6B, respectively. All these figures and following figures are graphs of the peak electric field in volts/meter as a function of the horizontal distance, X, in meters away from the antenna.
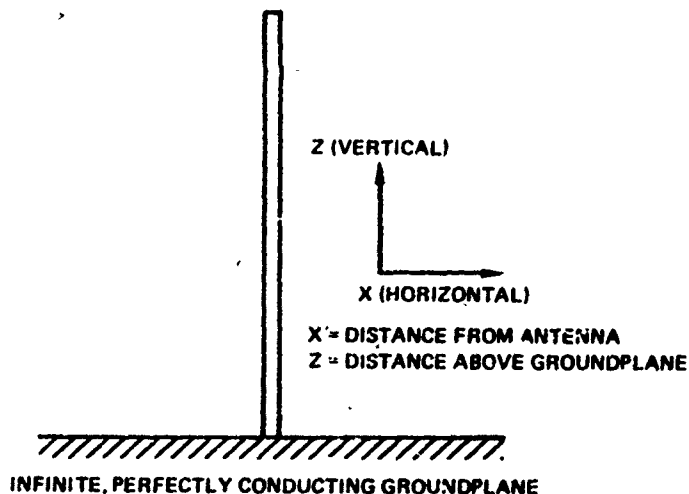
Z (VERTICAL)

X (HORIZONTAL)

X = DISTANCE FROM ANTENNA
Z = DISTANCE ABOVE GROUNDPLANE

INFINITE, PERFECTLY CONDUCTING GROUNDPLANE

Figure 3. Whip on an infinite, perfectly conducting groundplane; case 1: 35-ft whip, Ω = 12.5; and case 2: 17½-ft whip, Ω = 11.11.

A comparison of figures 4 through 6 indicates that close to the antenna the distribution of near fields varies with height. At frequencies 2 to 6 MHz, the greatest field distribution occurs at Z = 10 m. At higher frequencies, the location of the greatest distribution varies. This height variation of near fields with frequency maxima is related to the variation of the current distribution on the antenna with frequency and to the tendency of the groundplane to short out horizontal fields.

Apparently, RADHAZ to personnel from the case 1 arrangement will not be difficult to avoid. Only at 2 MHz does the 1000-V/m contour exceed 2 m from the antenna.

As discussed in a previous section, HERO SAFE ORDNANCE at hf requires that the electric field not exceed 100 V/m. Thus, an important parameter of any antenna arrangement is the horizontal distance away from the antenna at which the fields are less than 100 V/m. Such fields occur farthest from the antenna at 2 and 4 MHz, in spite of decreased efficiency. At 6 MHz, they are much closer to the antenna. For higher frequencies, the position of the 100-V/m limit varies, but again it is much closer to the antenna than at 2 and 4 MHz.

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EFFICIENCY
2 MHz ≈ 35.3%
4 MHz ≈ 80.0%
6 MHz ≈ 89.1%
10 MHz ≈ 39.5%

EFFICIENCY
15 MHz ≈ 88.9%
20 MHz ≈ 89.6%
25 MHz ≈ 90.0%
30 MHz ≈ 88.9%

Figure 4. Peak electric field at various frequencies (derated for coupler losses;
1.0 kW into coupler): case 1, $Z = 1.0$ m.

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EFFICIENCY
2 MHz = 35.3%
4 MHz = 80.0%
6 MHz = 89.1%
10 MHz = 89.5%

EFFICIENCY
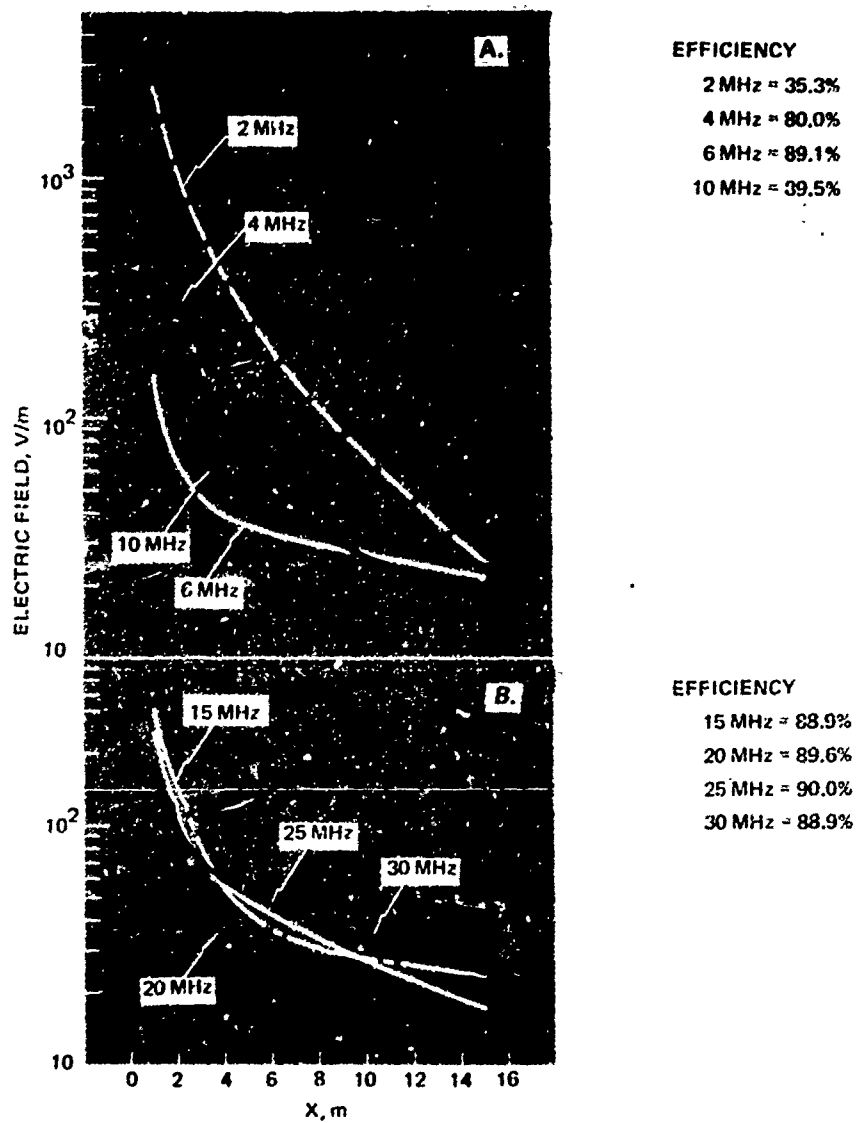15 MHz = 88.9%
20 MHz = 89.6%
25 MHz = 90.0%
30 MHz = 88.9%

Figure 5. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 1, $Z = 2.0$ m.

EFFICIENCY

2 MHz = 35.3%
4 MHz = 80.0%
6 MHz = 89.1%
10 MHz = 89.5%

EFFICIENCY

15 MHz = 88.9%
20 MHz = 89.6%
25 MHz = 90.0%
30 MHz = 88.9%

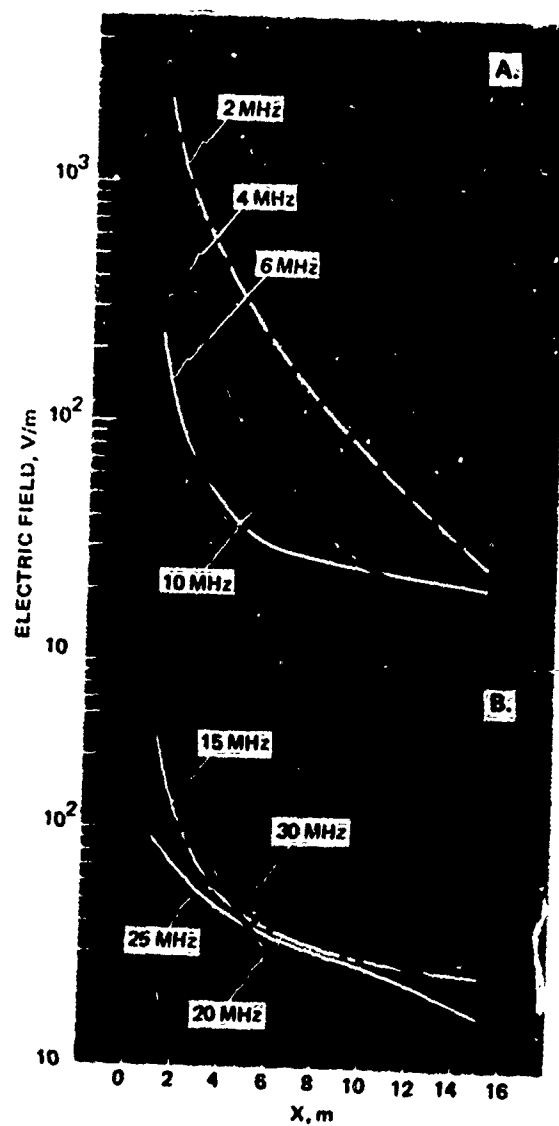Figure 6. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 1, Z = 10.0 m.

This variation of the near-field distribution with frequency can be related to two circumstances. It can be demonstrated by equation A-2 (see appendix A) that for a given radiated power the near-field distributions are inversely proportional to the distance away from the antenna in wavelengths. In wavelengths, 1 m is much closer to the antenna at 2 and 4 MHz than at the higher frequencies. This means the lower hf band will have greater near

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fields than the upper band. The other competing circumstance is that the near fields are minimal at resonances. For the 10.67-m whip, the first resonance occurs at approximately 7 MHz. There are several resonances from 7 MHz to 30 MHz. This explains the variation of the distance to the 100-V/m hazard limit at the higher frequencies.

17½-ft WHIP ON A GROUNDPLANE

This antenna arrangement, case 2, is also represented pictorially in figure 3. The results for this case are shown in figures 7 through 9. The frequencies 2, 4, 6, 10, and 15 MHz are considered with $Z = 1$ m in figure 7, $Z = 2$ m in figure 8, and $Z = 5.33$ m in figure 9. Figures 7 and 8 include the 2-MHz case 1 curves.

EFFICIENCY

2 MHz (CASE 1) = 35.3%
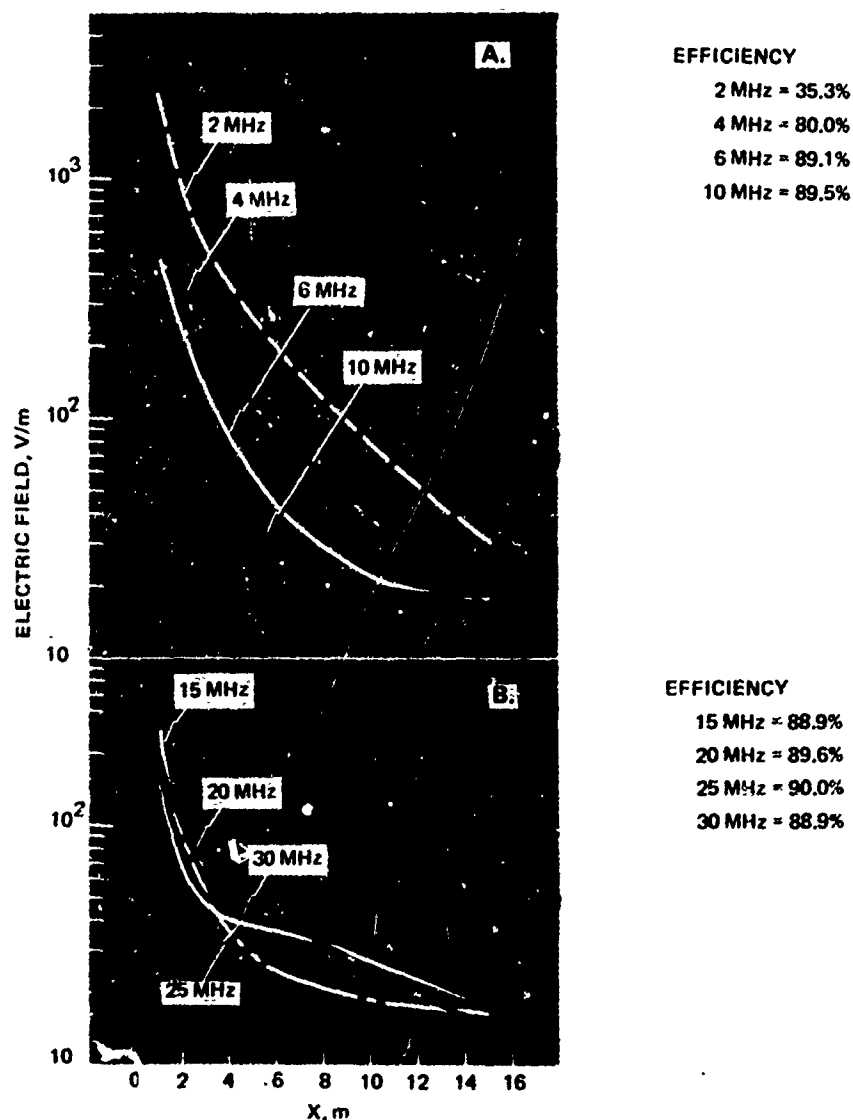2 MHz (CASE 2) = 7.3%
4 MHz = 39.5%
6 MHz = 68.3%
10 MHz = 87.2%
15 MHz = 89.6%

Figure 7. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 2, $Z = 1.0$ m.

This antenna qualifies as a low-profile, high-Q antenna. As should have been expected, the efficiency is substantially decreased at the lower hf frequencies. In spite of this efficiency decrease, these peak near fields in close to the antenna are greater than the case 1 near fields. Farther out from the antenna, the situation is reversed.

EFFICIENCY
2 MHz (CASE 1) = 35.3%
2 MHz (CASE 2) = 7.3%
4 MHz = 39.5%
6 MHz = 68.3%
10 MHz = 87.2%
15 MHz = 89.6%

Figure 8. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 2, Z = 2.0 m.

EFFICIENCY
2 MHz = 7.3%
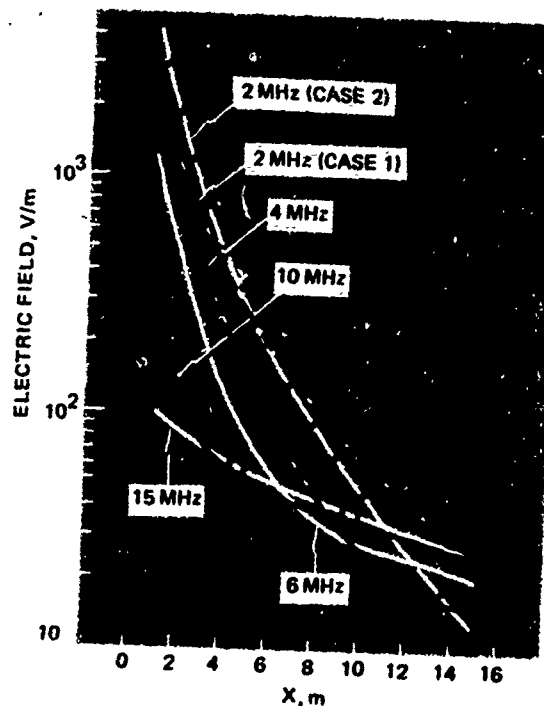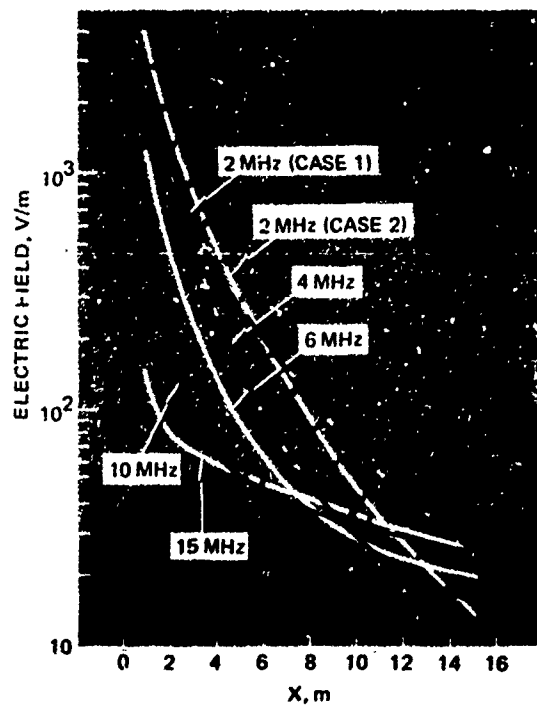4 MHz = 39.5%
6 MHz = 68.3%
10 MHz = 87.2 %
15 MHz = 89.6%

Figure 9. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 2, Z = 5.33 m.
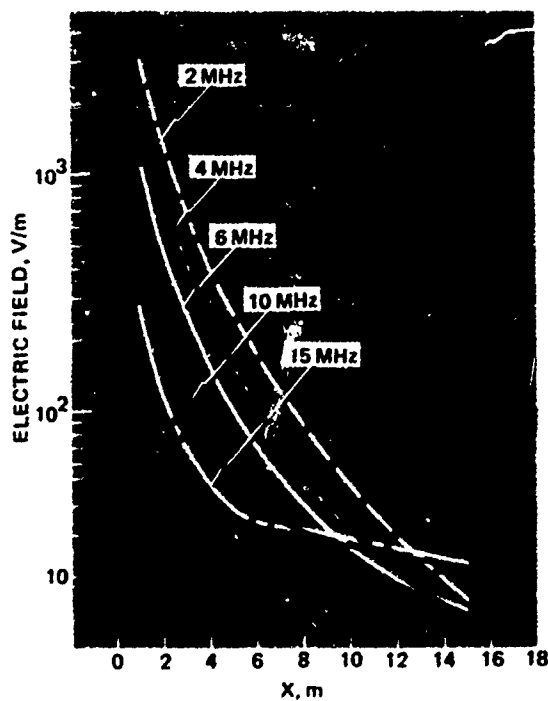
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These res lts substantiate the idea that the peak fields are substantially higher in the hf frequency range below the first resonant frequency. The first resonant frequency for the 17½-ft whip is approximately 14 MHz. Thus, 2, 4 and 6 MHz near fields are greater than the fields of the rest of the hf band.

At Z = 1 m, the distances from the antenna at which the 100-V/m hazard limit is encountered are somewhat different for case 2 than for case 1. The distances are essentially the same at 2 MHz. At 4 MHz, however, the case 2 distance increases from 4 to 6 m; at 6 MHz, it increases from 1.2 to 4.4 m. At 10 MHz, there is again a small increase. At 15 MHz, the distance decreases from 2.4 to 1.2 m · the first resonant frequency has been encountered.

WHIP ON A GROUNDPLANE AND NEAR A VERTICAL PLANE

Figure 10 is the pictorial representation of this case 3 antenna arrangement. Figures 11 through 15 are the results. The frequency is 2 MHz in all the figures. In figures 11 through 13, 4, 6, and 10 MHz are also considered. Five meters is the distance of the antenna from the vertical plane, D, in figures 11 through 13 and figure 15. In figure 14, D varies from 5 to 11 m. The vertical height is 1 m in figures 11, 14, and 15; Z = 2 m in figure 12 and 10.67 m in figure 13.

Again, the fields are substantially higher in the hf frequency range below the first resonant frequency. Also, the distances over which the electric fields exceed 100 V/m again increase over case 1. At both Z = 1 and 2 m, this increase varies from 0.5 to 1.5 m. Except at 6 MHz, Z = 1 m, the passageway between the wall and antenna has fields greater than 100 V/m for 2, 4, and 6 MHz.

X = DISTANCE FROM VERTICAL PLANE
Y = DISTANCE FROM ANTENNA AND ALONG VERTICAL PLANE
Z = DISTANCE ABOVE GROUNDPLANE

D = DISTANCE OF ANTENNA FROM VERTICAL PLANE

INFINITE, PERFECTLY CONDUCTING PLANES
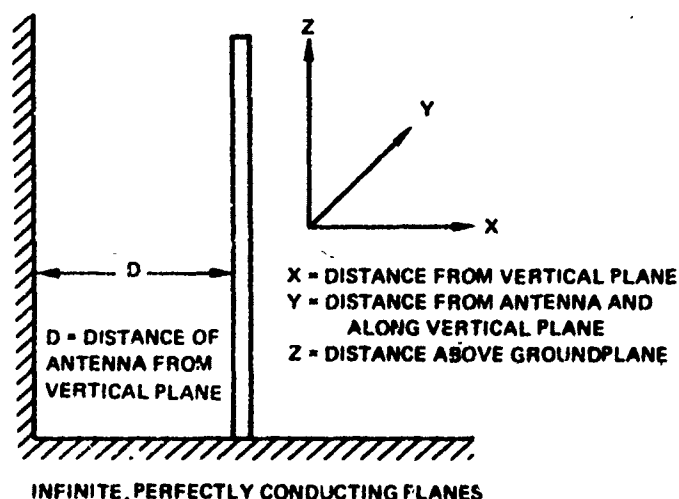
Figure 10. Whip on a groundplane and near a vertical plane; case 3: 35-ft whip, Ω = 12.5.
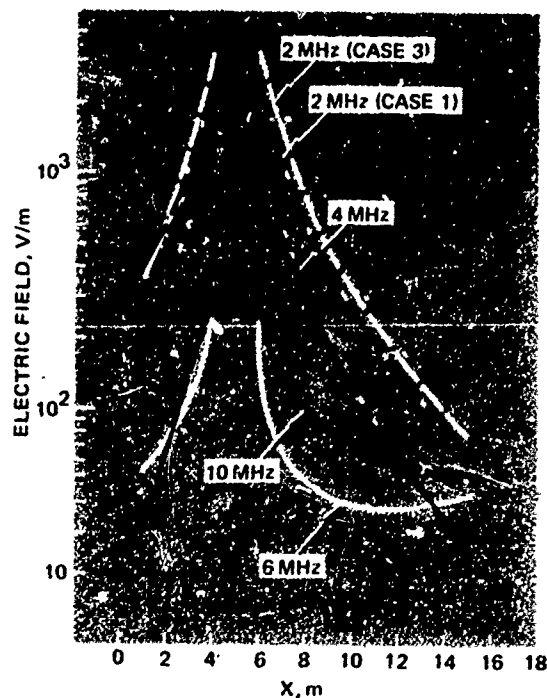
EFFICIENCY

2 MHz (CASE 1) = 35.3%
2 MHz (CASE 3) = 2.07%
4 MHz = 47.7%
6 MHz = 87.8%
10 MHz = 89.3%

Figure 11. Peak electric field at various frequencies (derated for coupler losses: 1.0 kW into coupler): case 3, Z = 1.0 m, Y = 0.0 m, D = 5.0 m.
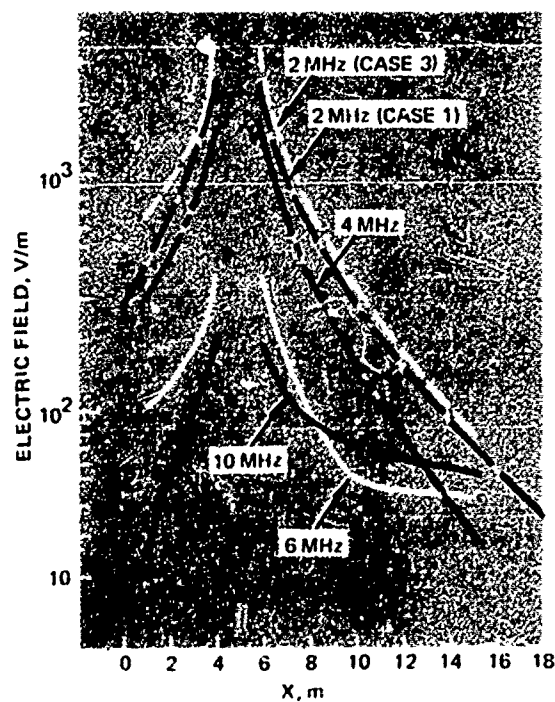
EFFICIENCY

2 MHz (CASE 1) = 35.3%
2 MHz (CASE 3) = 2.07%
4 MHz = 47.7%
6 MHz = 87.8%
10 MHz = 89.3%

Figure 12. Peak electric field at various frequencies (derated for coupler losses: 1.0 kW into coupler): case 3, Z = 2.0 m, Y = 0.0 m, D = 5.0 m.

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EFFICIENCY
2 MHz ≠ 2.07%
4 MHz ≈ 47.7%
6 MHz ≈ 87.8%
10 MHz ≈ 89.3%

Figure 13. Peak electric field at various frequencies (derated for coupler losses; 1.0 kW into coupler); case 3, Z = 10.67 m, Y = 0.0 m, D = 5.0 m.
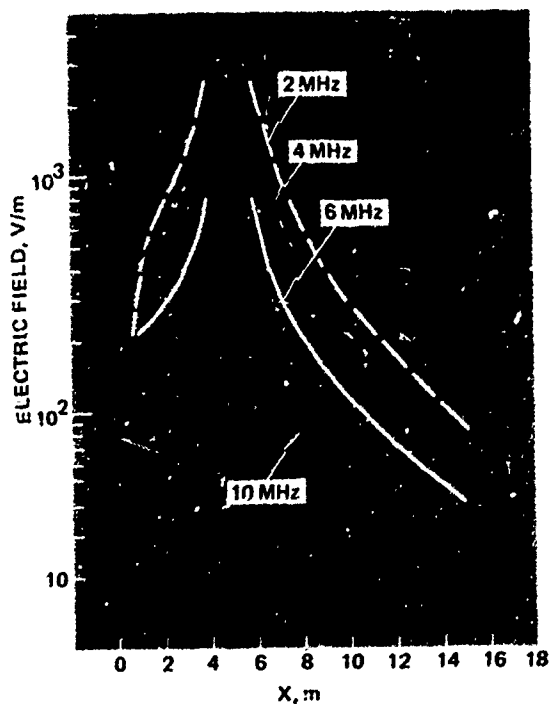
EFFICIENCY
——— D = 5.0 m = 2.07%
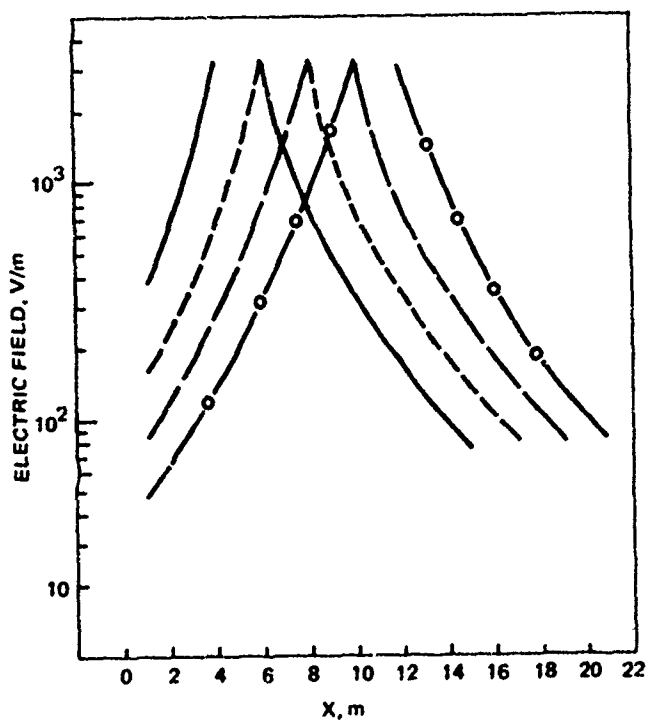—●— D = 7.0 m = 3.88%
—●— D = 9.0 m = 6.13%
—o— D = 11.0 m = 8.71%

Figure 14. Peak electric field for various D (derated for coupler losses; 1.0 kW into coupler); case 3, Z = 1.0 m, Y = 0.0 m, freq = 2 MHz.
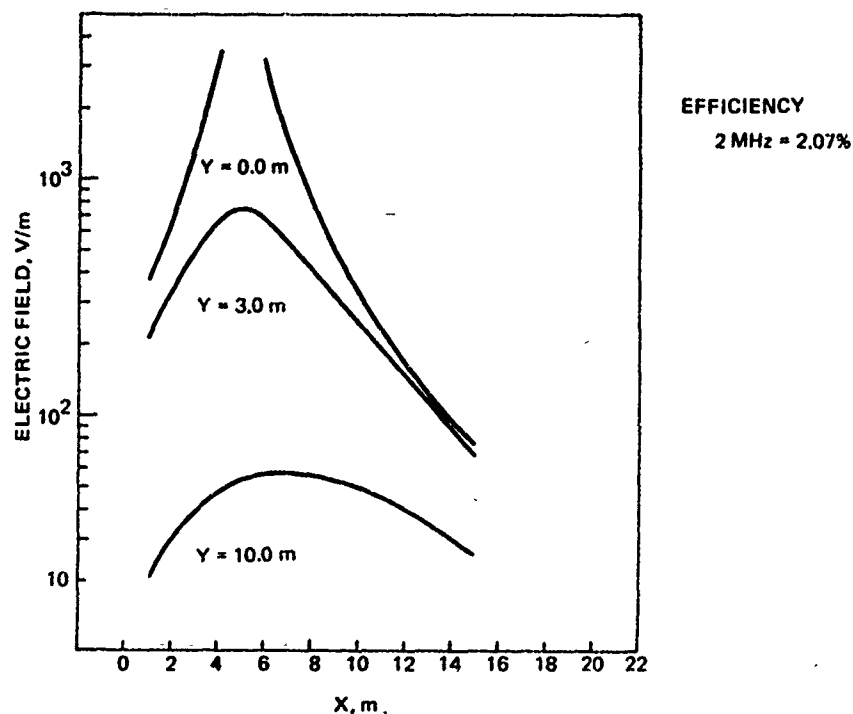
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Figure 15. Peak electric field for various Y (derated for coupler losses; 1.0 kW into coupler); case 3, Z = 1.0 m, D = 5.0 m, freq = 2 MHz.

Figure 15 demonstrates how the field strengths decrease on the Y axis away from the antenna. In figure 14, a 2-MHz antenna is moved away from the wall. The efficiency increases. The field strengths in close to the wall decrease. However, the 100-V/m-hazard-limit distances away from the antenna stay approximately the same.

WHIP ON A GROUNDPLANE AND NEAR TWO VERTICAL INTER-SECTING PLANES

This arrangement is case 4 (fig. 16). Figures 17 through 21 are the results. Z = 1 m in all these figures. The antenna is 5 m away from both vertical planes in figure 17, and 11 m away in figures 18 through 21. The frequency is 2 MHz in figures 17 and 18; it is 4 MHz in figure 19, 6 MHz in figure 20, and 10 MHz in figure 21.

According to figure 17, at 2 MHz and 5 m from both vertical planes, the efficiency is only 0.04%. At this efficiency, the structure is no longer operating as an antenna. Even when the antenna is moved to 11 m away from both vertical phases (fig. 18), there is no improvement in the efficiency.

At 4 MHz (fig. 19), there is also a decrease in efficiency from the case 1 condition, but it is not sufficient to limit the operation of the antenna.

Again, in close to the antenna, the near-field distribution is greater than in case 1. The 100-V/m-limit distance again increases. However, at 2, 4, 6, and 10 MHz, this increase is only 0.5 to 1.5 m.

The fields are not symmetrical with respect to the antenna on the Y axis. Their position is a complicated function of frequency and antenna position. However, in general the fields are less in the direction of the plane than away from it.

TOP VIEW

X = DISTANCE FROM VERTICAL PLANE
Y = DISTANCE FROM VERTICAL PLANE

INFINITE, PERFECTLY CONDUCTING PLANES
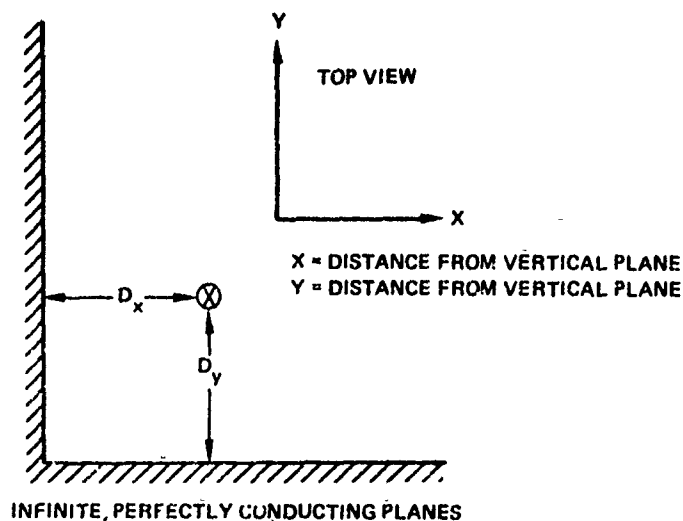
Figure 16. Whip on a groundplane and near two vertical intersecting planes; case 4: 35-ft whip, $\Omega = 12.5$.

EFFICIENCY
2 MHz (CASE 4) = 0.04%
2 MHz (CASE 1) = 35.3%

Figure 17. Peak electric field for various Y (derated for coupler losses: 1.0 kW into coupler): case 4, Z = 1.0 m, (D_x, D_y) = (5 m, 5 m), freq = 2 MHz.

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Figure 18. Peak electric field for various Y (derated for coupler losses; 1.0 kW into coupler); case 4, $Z = 1.0$ m, $(D_x, D_y) = (11$ m, 11 m), freq = 2 MHz.
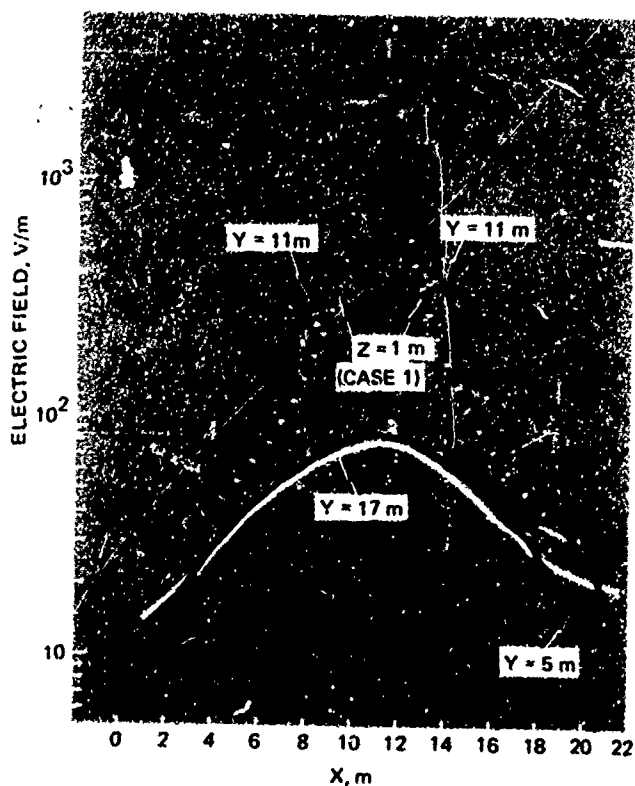
Figure 19. Peak electric field for various Y (derated for coupler losses; 1.0 kW into coupler); case 4, $Z = 1.0$ m, $(D_x, D_y) = 11$ m, 11 m), freq = 4 MHz.

EFFICIENCY
6 MHz (CASE 4) = 89.39%
6 MHz (CASE 1) = 89.1%

Figure 20. Peak electric field for various Y (derated for coupler losses; 1.0 kW into coupler); case 4, $Z = 1.0$ m, $(D_x, D_y) = (11$ m, 11 m), freq = 6 MHz.

EFFICIENCY
10 MHz (CASE 1) = 89.5%
10 MHz (CASE 4) = 89.8%
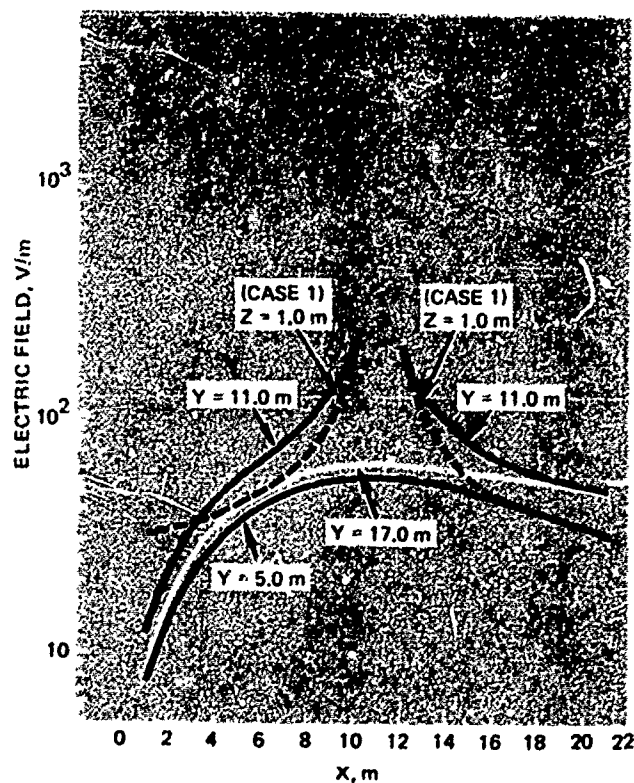
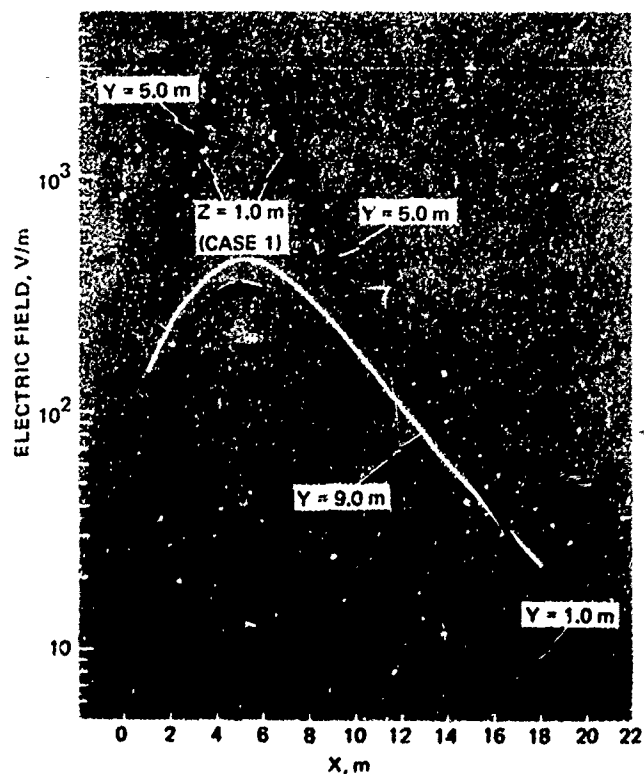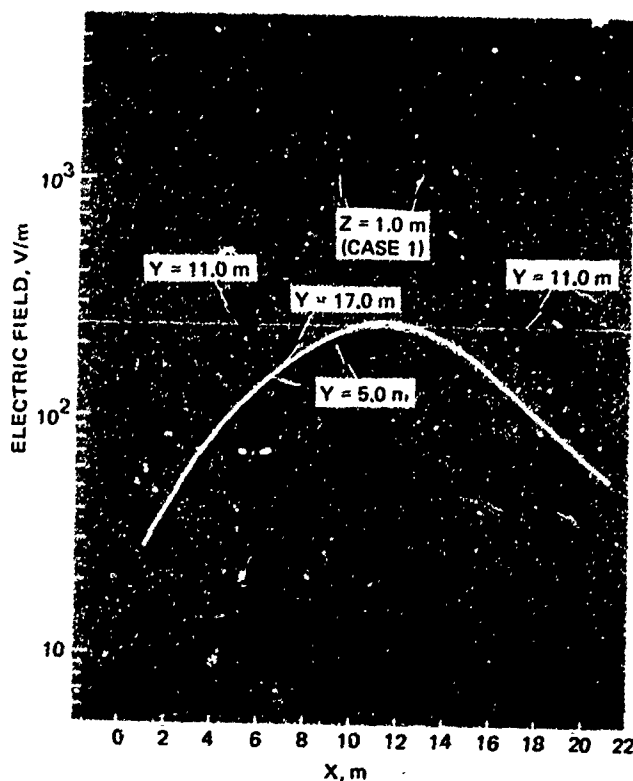Figure 21. Peak electric field for various Y (derated for coupler losses; 1.0 kW into coupler); case 4, $Z = 1.0$ m, $(D_x, D_y) = (11$ m, 11 m), freq = 10 MHz.
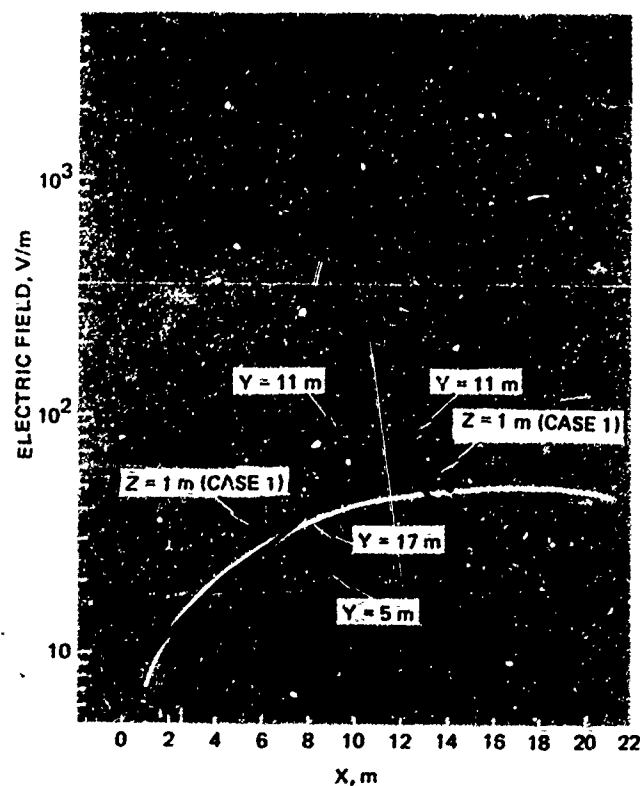
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CONCLUSIONS

1. There exists a definite radiation hazard to personnel and ordnance due to shipboard hf radiators.

2. The hazard is greatest in the lower hf band below the first resonance of the radiator in question.

3. The hazard is least at the antenna's natural resonance frequency.

4. The hazardous region surrounding the antenna is not a strong function of the structure surrounding the antenna.

5. If an antenna is shortened, the radiation hazard is increased.

6. Surrounding structure can cause a substantial decrease in efficiency for those frequencies below the first resonance.

7. The maximum radii of the 1000-V/m contour (RADHAZ to personnel) and the 100-V/m contour (HERO) are given in tables 1 and 2.

TABLE 1. MAXIMUM RADIUS (IN METERS) OF 1000-V/m CONTOUR
AS A FUNCTION OF LOWEST FREQUENCY TRANSMITTED.

	Vertical Height	2 MHz	4 MHz	6 MHz
CASE 1	1 m	2.0	1.0	--
	2 m	2.0	1.0	--
	10 m	1.8	1.0	--
CASE 2	1 m	2.6	1.8	1.1
	2 m	2.7	1.9	1.2
	5.33 m	2.4	1.6	1.0
CASE 3	1 m	2.6	1.4	1.0*
	2 m	2.6	1.4	1.0
	10.67 m	2.2	1.6	1.0
CASE 4	1 m (D=5 m)	2.6	--	--
	1 m (D=11 m)	2.8	1.3	1.0

*Indicates maximum radius determined by a frequency other than the lowest frequency transmitted.

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TABLE 2. MAXIMUM RADIUS (IN METERS) OF 100-V/m CONTOUR AS A FUNCTION OF LOWEST FREQUENCY TRANSMITTED.

	Vertical Height	2 MHz	4 MHz	6 MHz
CASE 1	1 m	8.4	4.0	2.4*
	2 m	8.6	4.3	2.8*
	10 m	8.8	5.5	2.6*
CASE 2	1 m	7.6	5.9	4.4
	2 m	6.8	6.0	4.7
	5.33 m	6.8	6.2	5.0
CASE 3	1 m	9.0	5.7	3.0*
	2 m	9.1	6.2	3.0
	10.67	9.2	5.5	2.6
CASE 4	1 m	8.0	---	---
	1 m	9.4	5.4	1.2

*Indicates maximum radius determined by a frequency other than the lowest frequency transmitted

RECOMMENDATIONS

1. Provide a hazard zone around each antenna to ensure that personnel and ordnance are not exposed to hazardous field intensities. Based on the preliminary data in this report, recommendations as to the size of the safe zone for 35-ft transmitting whip antennas are given in tables 3 and 4.

TABLE 3. RECOMMENDED RADIUS OF ORDNANCE HAZARD ZONE (MAXIMUM 100-V/m CONTOUR) FOR 35-ft WHIPS* AS A FUNCTION OF LOWEST FREQUENCY TRANSMITTED.

Lowest Frequency Transmitted, MHz	Radius of Hazard Zone, m
2	9.4
4	6.2
6	2.8

*Connected to transmitters with available output power of 1 kW or less.

TABLE 4. RECOMMENDED RADIUS OF PERSONNEL HAZARD ZONE (MAXIMUM
1000-V/m CONTOUR) FOR 35-ft WHIPS* AS A FUNCTION OF LOWEST
FREQUENCY TRANSMITTED.

Lowest Frequency Transmitted, MHz	Radius of Hazard Zone, m
2	2.8
4	1.6
6	1.0

*Connected to transmitters with available output power of 1 kW or less.

    2. Verify by measurement the validity of the calculations reported here.

    3. Determine the near fields of other Navy shipboard antennas, such as (1) other length whips, (2) edge-mounted whips, (3) twin whips, (4) discone/ discage antennas, and (5) fan antennas. The latter three antennas are more likely to be used in the lower frequency range, where the potential hazards are greatest.

    4. Develop simplified design charts based on the results of 3, to detail the minimum hazard-zone radius for each type of shipboard antenna for the various possible mounting configurations.

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APPENDIX A: ELECTROMAGNETIC FIELD OF A
LINEAR CURRENT ELEMENT

The near field of any antenna is in general very complex. Consider a linear current element $I = I_0 e^{jwt}$ of length Δz, oriented in the Z direction and located at the origin, as in figure A-1. For convenience, assume I_0 is a real amplitude factor. This antenna is a simple radiating structure, but it will demonstrate the properties of the near field of all antennas.
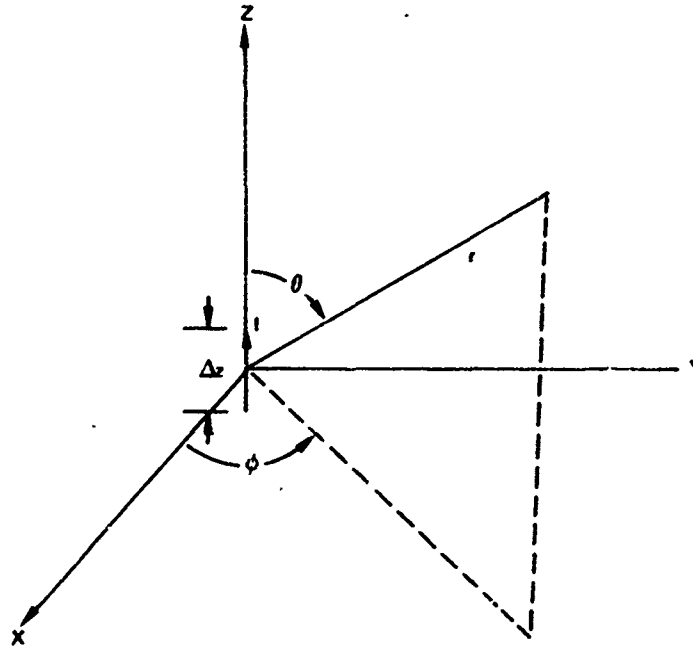

Figure A-1. A linear current radiator.

The complete magnetic-field intensity of the antenna is [16]

$$\bar{H} = \frac{I_0 \Delta z}{4\pi} \sin \theta \left(\frac{jk_0}{r} + \frac{1}{r^2} \right) e^{-jk_0 r} \; i_\phi \tag{A1}$$

The complete electric-field intensity of the antenna is

$$\bar{E} = \frac{-I_0 \Delta z}{2\pi} \; j \; \frac{\mu_0^{1/2}}{k_0 \epsilon_0^{1/2}} \cos \theta \left(\frac{jk_0}{r^2} + \frac{1}{r^3} \right) e^{-ik_0 r} \; i_r$$

$$\frac{-I_0 \Delta z}{4\pi} \; j \; \frac{\mu_0^{1/2}}{k \epsilon_0^{1/2}} \sin \theta \left(\frac{-k_0^2}{r} + \frac{ik_0}{r^2} + \frac{1}{r^3} \right) e^{-ik_0 r} \; i_\theta \tag{A2}$$

The total average power radiated into space by the current element is given by

$$P_r = \frac{(k_0 I_0 \Delta z)^2}{12\pi} Z_0$$

where

$$Z_0 = \frac{\sqrt{\mu_0}}{\epsilon_0}$$

The only part of the fields entering into this expression for the radiated power is that part consisting of the terms varying as r^{-1}: that is,

$$H_\phi = \frac{jk_0 I_0 \Delta z}{4\pi r} \sin \theta \ e^{-jk_0 r} \tag{A3}$$

$$E_\theta = \frac{jk_0 I_0 \Delta z}{4\pi r} \sin \theta \ e^{-jk_0 r} \tag{A4}$$

This part of the field is called the radiation field. For large values of r, it is the only part of the total field which has a significant amplitude. The part of the field varying as r^{-2} and r^{-3} is called the induction field. The induction field does not represent an outward flow of power, but instead gives rise to a storage of reactive energy in the vicinity of the radiating current element.

The radiation components of the electric and magnetic fields are in phase with each other. In the near field, the phase relationship is very complicated. The polarization of the far field is generally elliptical, whereas the polarization of the near field is generally ellipsoidal.

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